Bellcomm

955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

B71 11020

date: November 17, 1971

to: Distribution

from: N. P. Patterson

subject: Astronomy on the Shuttle Sortie
Case 236

ABSTRACT

The objectives and instrumental requirements of space astronomy are reviewed and the usefulness of the shuttle sortie to astronomy is evaluated.

The sortie program is compared with current and planned space astronomy programs and it is concluded that the sortie mode could support a large part of space astronomy research for the foreseeable future. It would play a leading role in the development of very large orbiting observatories and a complementary role in their use.

Rocket-class instruments are foreseen as a major source of sortie experiments.

Although astronomy experiments place a number of critical requirements on the shuttle vehicle and experiment modules, there do not appear to be any significant limitations on the sortie's potential value to astronomy if these requirements are considered in the early design of the system.

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MEMORANDUM FOR FILE

I. Introduction

The purpose of this study is to evaluate the potential usefulness of the space shuttle to the field of astronomy. In particular, the sortie mode is considered as one of the available options for conducting observations in space.

Because the advent of the space shuttle is expected to make space flight routine and because space observations are of great importance to astronomical research, we wish to determine whether the sortie mode of shuttle operation, with its promise of lower experiment costs, will be of significant value to astronomy.

From a review of the objectives of astronomy, the instruments likely to be of most usefulness and the alternative programs available, it is concluded that the sortie mode could be of very great value to astronomy for an indefinite period.

Some of the advantages of the sortie are discussed to indicate why it appears to be so attractive for astronomy purposes. The likely demand for its services is considered and the impact of astronomy activity on the design and operation of the shuttle vehicle and experiment modules is suggested.

(a) Astronomy

Astronomy is concerned with celestial bodies — the sun, planets, stars, groups of stars, and clouds of gas and dust — making up the universe. It entails the observation of radiation reaching the earth from sources which are beyond our immediate reach.

The goal of astronomy is to enlarge our understanding of the universe we are a part of. The material and energy it contains and the diverse states in which they exist are studied

to understand the processes which determine their behavior and have caused the universe to be brought to its present form.

The exotic phenomena and the wide range of conditions which are observed provide test situations for scientific theories in a larger domain than is available on the earth. The application of established physical laws to unusual circumstances provides a new perspective and deeper understanding of both, often leading to the discovery of new laws and phenomena. For example, the study of nuclear processes may benefit from the search for hypothetical neutron stars as much as the study of atomic processes has benefited from observations of stellar atmospheres.

Because of its universal appeal, astronomy exerts a major influence on the conceptual and technological growth of civilization. It is a field in which scientists of many disciplines (physics, chemistry, geology, biology and mathematics) are enthusiastically involved, and it has traditionally evoked the highest degree of philosophical speculation, technological development, and international cooperation. Astronomy is both an exciting field of discovery and a long-term investment in the future, with rich scientific and cultural dividends.

(b) Space Astronomy

A number of studies have been made of the objectives of astronomy and the potential value of space observations (1-12) They have concluded that the elimination of atmospheric effects which limit ground observations (absorption, emission, distortion and scattered light- all fluctuating) promises to revolutionize the field of astronomy. The extension of observations to the entire electromagnetic spectrum, and the great improvement in the resolution and signal-to-noise made possible by space flight is expected to have a profound effect on every aspect of astronomy. The significance of these benefits is suggested by the dramatic advances recently made possible by developments in radio astronomy and rocket observations, and their correlation with visible observations. Gamma-ray, x-ray and far-infrared sources could not have been discovered with ground-based instruments.

Up to the present it has been necessary to expend an extravagant proportion of the effort involved in obtaining space observations overcoming instrument problems arising from size, weight, time and operational restrictions on instrument

payloads. In contrast, ground-based radio-astronomy, another relatively new technique which is not encumbered by such restrictions, is developing at a rapid rate for a much lower cost. The entire discipline of astronomy is ripe for significant breakthroughs which could be realized if access to space were more easily available. The shuttle sortie might become a standard observing platform for space astronomy.

(c) Space Shuttle Sortie

The development of the manned space shuttle is expected to have a dramatic effect on the way that scientific experiments, including astronomical observations, can be conducted in space (14-17).

Several of the envisioned uses of the shuttle would be valuable to space astronomy. As a logistics vehicle it could launch and deploy astronomy satellites, recover and return them to earth or service them in orbit. Engineering aspects of these shuttle functions for space observatories have been studied in detail (18-20).

A second mode of shuttle operation, the short-term "sortie" (analogous to those conducted in the NASA aircraft program (15, 21)) is the subject of this study. On this type of flight the shuttle payload would consist of one or two cylindrical experiment modules $\sim$15 feet in diameter and 15-60 feet in length (See Figure 1).

One type of cylinder, a "general purpose module" (GPM) would be essentially an empty can into which are mounted a life support system, passenger couches and work spaces for a variety of scientific instruments. The second type of module, a "dedicated module" (DM), designed especially for a single purpose (e.g., astronomy) or instrument, might fly at the same time. Both types could be used for astronomical observations if airlocks were available in the wall of the modules (See Figure 2). Other payloads, such as small satellites to be deployed, might be carried on the same flight.

Typically, the GPM would carry a number of experiments which could be conducted independently. The individual instruments, sometimes referred to as "laboratory-class" and "suitcase" instruments, would be carried aboard just prior to flight. They would not be required to meet stringent space flight standards of reliability and might resemble rocket payloads and individual instruments now flown "piggyback" on

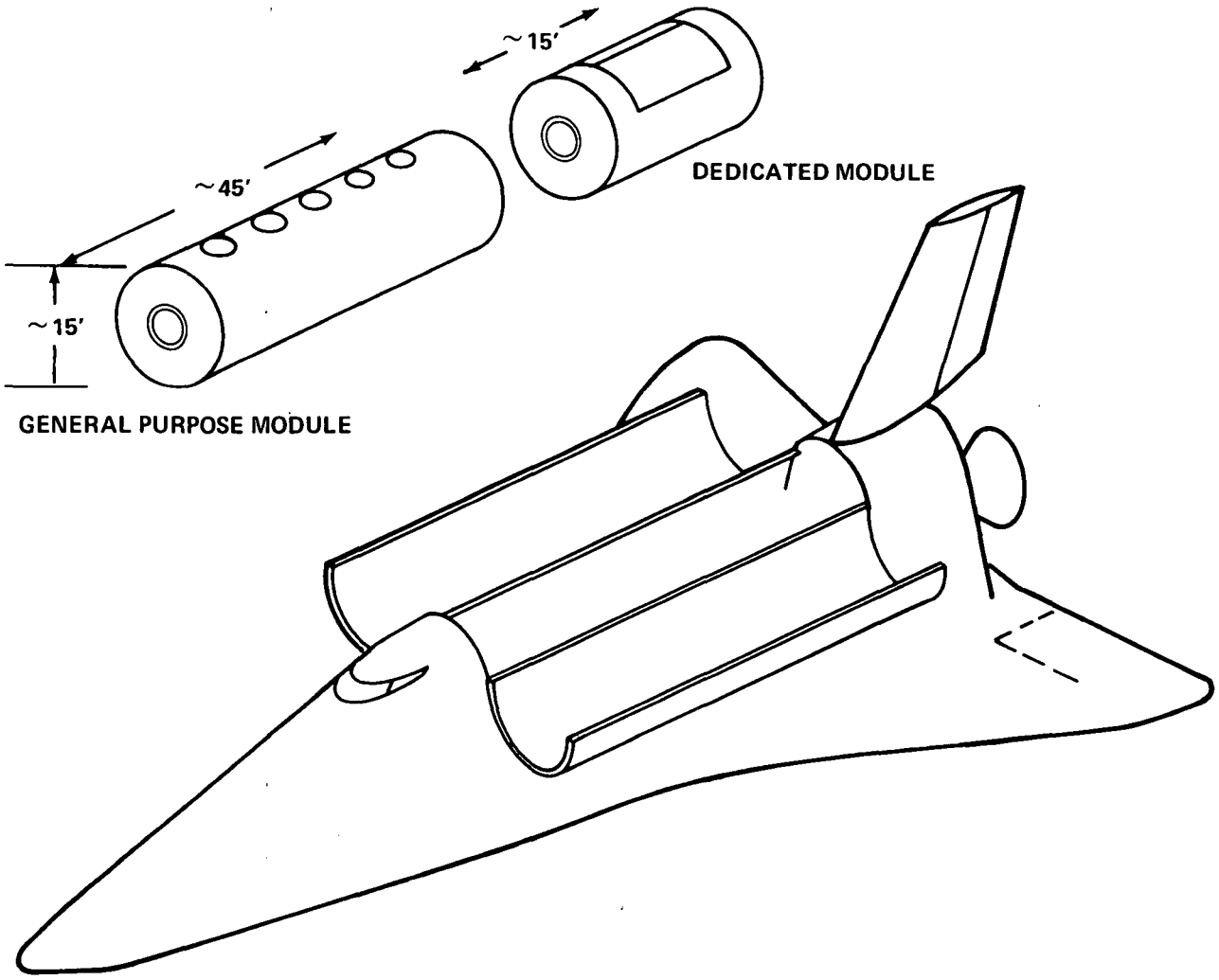

FIGURE 1 - SHUTTLE SORTIE EXPERIMENT MODULES

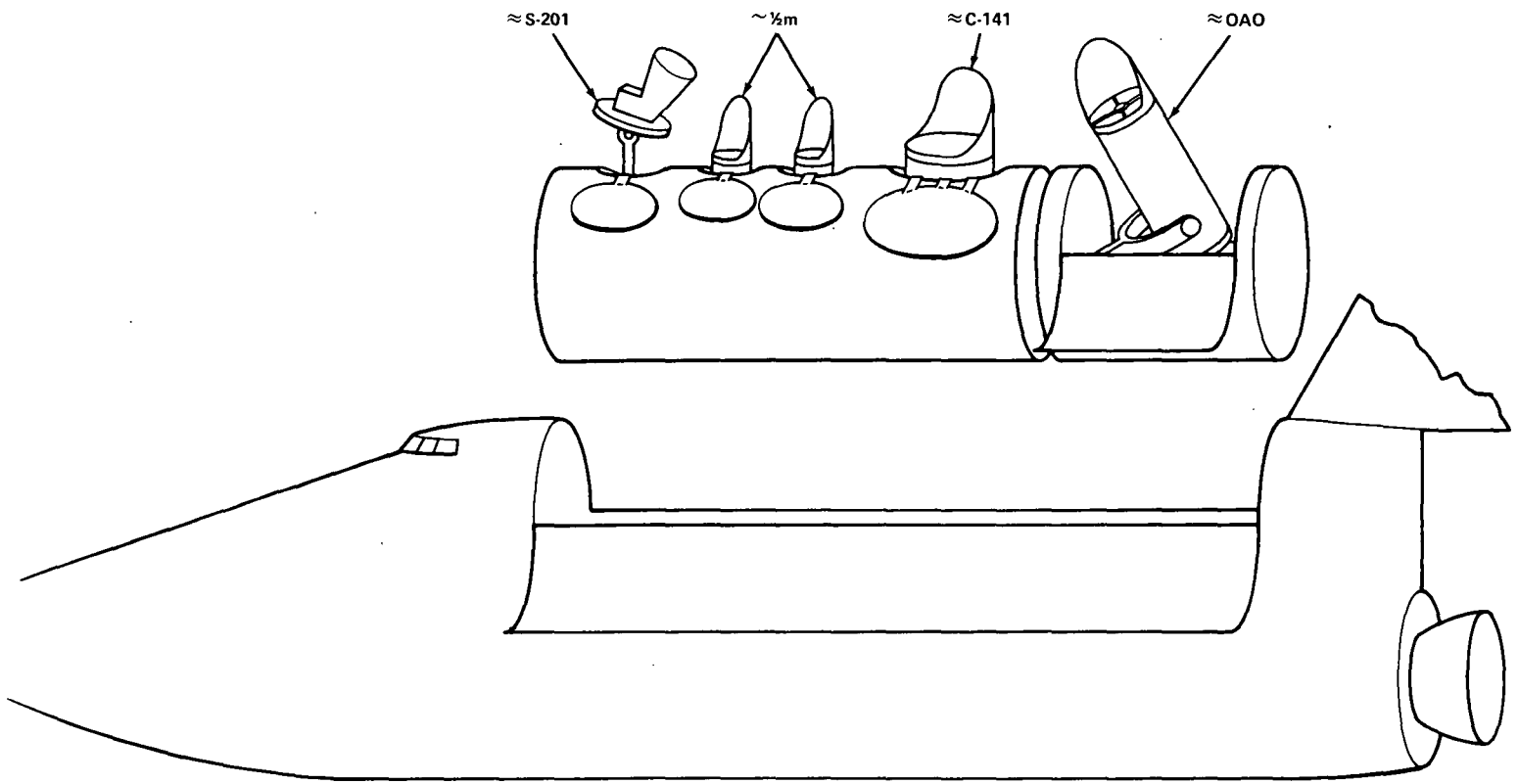

FIGURE 2 - EXPERIMENT MODULES FOR SPACE ASTRONOMY

unmanned satellites. The DM would be reserved for larger, more complex instruments, similar to an OAO in sophistication, operated by remote control from the GPM.

Many benefits are anticipated from this program (17), including: on-board experimenters, frequent flight opportunities, liberal size and weight allowances, relaxed reliability requirements, low instrument costs, simple interfaces, low acceleration observations, flexible operations.

II. Astronomical Objectives

In order to determine the effectiveness of the shuttle sortie for astronomy it is necessary to know what information will be sought and how it is likely to be acquired in the period when the shuttle will become operational (c.1980).

A partial list of the many objectives which have been suggested for space astronomy experiments appears in Appendix 1. The diversity of these studies is very broad.

The sizes of objects of interest range from tiny dust particles to giant stellar aggregations. Targets vary in brightness and proximity, ranging from the sun to the faintest detectable galaxies. The physical processes of interest include the action of weak galactic magnetic fields as well as explosive events in the cores of galaxies.

One of the most important objectives is considered to be an understanding of the cosmological questions(1,9). Our understanding of the nature and organization of objects of smaller scale rests upon this foundation. Because attaining this understanding requires a detailed knowledge of closer, more clearly viewed objects, they must be studied as well.

In probing the universe, observations in all spectral ranges should be pursued with equal vigor since different physical processes are more suitably studied in different parts of the spectrum. For example, a discovery made in one wavelength range (because of some fortuitous combination of factors) may yield even deeper insights in other ranges. It is important, therefore, to be able to follow up discoveries by observations over as much of the spectrum as possible.

In each of the spectral ranges detectable only from above the atmosphere, all-sky surveys are necessary to determine anisotropies in the background emission and the location of individual sources. Selected sky regions must be mapped to fainter limits at higher resolution, and special objects will

have to be examined and monitored in detail. There is a need, then, for several levels of sensitivity and angular resolution. The same holds true in spectral studies where initial broad-band measurements lead to scans of continuum distributions and high resolution emission and absorption line-profile studies. This pattern now occurs across the entire spectrum from plasma oscillation frequencies in long wave radio bands to nuclear transition line energies in the γ-ray range.

Astronomical research consists therefore of a mixture of overlapping objectives in every spectral range, at various stages of maturity.

In general, astronomers seek to determine a number of characteristics for any object (size, distance, motion, chemical composition, temperature and density distribution, age, history, forces acting on it), and its relationship to other objects in its neighborhood and to other objects of similar and different classifications distributed throughout the universe. A particular experiment may examine several characteristics of one object or one class of objects, or, alternatively, examine one particular characteristic of many different classes.

Data from which these many characteristics are inferred is obtained by collection of photons from the object, and subsequent analysis of their flux, time variations, energy or spectral distribution, polarization and direction. (charged particles and micrometeoritic dust are also studied by astronomers but these topics are covered in other papers on Cosmic Ray Physics and General Science in this series of reports on the use of the shuttle in the sortie mode (13)). Typically, the radiation is collected by a telescope or array feeding auxiliary instruments carrying detectors which record spatial images, scans, spectrophotometric data and spectral-time variations. Telescopes are sometimes uniquely configured for specialized purposes, but many are adaptable to a variety of purposes. The objectives of space astronomers are often compiled in terms of their instrument requirements rather than their observing programs.

III. Instrumental Requirements

A variety of optical systems, antenna arrays, detectors and auxiliary instruments are available to ground astronomers. There is presently a trend toward automation of routine operations (e.g. setting the telescope) and integration of data outputs with digital convertors and computers, permitting more efficient use of observing time and application of powerful image-processing techniques such as aperture synthesis and image averaging.

Space instrumentation is marked by the same diversity. Appendix 2 contains a list of instruments typical of those suggested for space observations. Most are adaptations to x-ray, ultraviolet and infrared wavelength operation of ground-based visible telescope concepts, designs and hardware of proven value. Desirable performance would include high pointing stability and angular resolution, long exposure duration and large collecting area. In addition, there must be access to the space vacuum.

Rockets permit relatively low-cost observations in space with a variety of instruments. Because the rocket program is so productive, an expansion in the program has been given the highest priority for the foreseeable future (9,10).

For exploratory purposes, small, simple instruments are adequate. With observational success, however, improved instruments are needed. The usefulness of very small telescopes ($\lesssim$6") and arrays will probably have been fully exploited in rocket and automated satellite programs by the time the shuttle is available. This is particularly likely in the x-ray range (because of the SAS and HEAO programs). In the infrared, technical complexities of cryogenically cooling satellite telescopes may delay exploratory satellite surveys. Different studies require different instrument capabilities, but in space, there will be strong dependence upon aperture size of almost every measure of ultimate performance (an exception is useful field-of-view). A larger aperture provides better angular resolution, finer spectral resolution and, for a given integration time, higher signal-to-noise. Aperture size is therefore the fundamental measure of what can be achieved, with a space telescope. The availability of increased integration time and improved detector efficiency offers considerable relief from the restriction on collecting area, however.

Because the ability to make new discoveries and interpretations depends directly on aperture size in space, the most desirable instruments are an advanced solar telescope (ASO), a sophisticated, near-diffraction-limited optical telescope (LST) and a large x-ray imaging telescope (OXO). The suggested aperture sizes are $\sim$1m, 3m and 5m, respectively (9,10).

However, in space, as on the ground, telescopes of intermediate size are needed (1,5,6). Auxiliary instrumentation is readily interchangeable between the two classes and most development work, both technological and observational is first done on smaller telescopes. New techniques are debugged and then exploited on smaller telescopes before being transferred to the largest telescopes, where observing time is at a premium.

In the era of the shuttle, the following standards

of performance are not likely to have been made obsolete by the space experiments now being planned:

Solar	Angular resolution	$\sim 0.5''$
	Spectral resolution	~ 0.01Å
	Pointing accuracy & stability	$\sim 0.5''$
Stellar/Planetary	Angular resolution	$\sim 0.2''$
	Spectral resolution	~ 0.1Å
	"Limiting magnitude"	$\sim 12m_v$
X-ray	Collimated arrays	$\sim 10m^2$
	Angular resolution	$\sim 2''$
	Energy resolution	$\sim 0.1\%$
	Polarization	$\sim 1\%$
γ-ray	Collimated arrays	$\sim 10m^2$
	Angular resolution	$\sim 0.1^\circ$
	Energy resolution	$\sim 30\%$
IR	Angular resolution	$\sim 10''$ (@$\lambda \sim 50\mu$)

The aperture size required to achieve these standards varies, and would depend upon such factors as wavelength, optical precision, brightness of the object, pointing stability, background brightness, and detector efficiency and resolution. In special cases, rocket instruments costing ~$200K (payload weight ~300#, aperture size ~0.3m) have already provided some data of this quality. For cosmological studies, however, such as the detailed study of distant galaxies, the largest observatories feasible will be needed. These large instruments, together with their refined auxiliary instruments would weigh anywhere from 2000lbs to 25,000lbs depending on the approach taken to assure their reliability and versatility. Cost estimates range up to $\$10^9$ for an LST. They will require long-term (10-20 yrs) development in order to reach ultimate performance and it is unlikely that they will be developed as expendable satellite payloads.

In space, an optical telescope can observe in the UV and IR, it is unhindered by weather and atmospheric seeing and it can make exposures many hours in duration. Even if it were not nearly diffraction-limited, it could reasonably be given a value equivalent to a much larger ground-based telescope. If it approaches diffraction-limited performance, (figure precision $\sim\lambda/50$) it's angular resolution would be as good as that of a mirror about 2.5 times larger which has a figure precision of only Rayleigh's Limit ($\lambda/4$).

In the following classification of ground-based telescopes it is proposed that a 2m diameter telescope is currently capable of a full range of visible observations, and that the few telescopes larger than about 4m are most valuable for research at the cosmological frontiers.

Aperture Size	Research Value	Cost (1)	Development
Giant, $\gtrsim$ 250"	(Feasible)?	$100M?	$\sim$15 yrs. ?
Very Large, $\gtrsim$ 150"	Frontier	$\sim$ 20M	$\sim$ 8 yrs.
Large, $\gtrsim$ 80"	Full Research	$\sim$ 2M	
Intermediate, $\gtrsim$ 40"	Special Research	$\sim$0.5M	$\sim$ 1 yr.
Small, 16" - 24"	Solar/Educational	$\sim$0.2M	< 1 yr.

On this basis, 1/2m to 1m space telescopes (near-diffraction-limited) would be capable of a full range of research for some time to come. A 1/2m UV telescope could resolve to better than 0.3" and detect class AO stars (over 1350-1450Å) as faint as 12^m_V. It is certain, however, that in a successful program there will be a desire for larger telescopes. The cost of size can be expected to rise at a much more rapid rate than the performance, however.

In summary, it will be important to have a large number of space instruments of varying degrees of sophistication, between breadboard and fully automated, performing studies ranging from exploratory to detailed.

The space astronomy program should be able to accommodate this diversity of equipment and observations and be adaptable to unpredictable technical developments and new ideas.

IV. Impact of Shuttle on Space Astronomy

Astronomy experiments are now being conducted from suborbital platforms and unmanned satellites and will continue to be after the shuttle comes into operation. Can the shuttle sortie program be an attractive option for astronomy experiments?

Experience on manned and unmanned spacecraft indicates that they both have imposed limitations and burdens on experiments which could be relieved with the shuttle. Many functions could be carried out on a sortie flight.

a) Non-Sortie A summary of current programs involving astronomy experiments is outlined in Appendix 3.

A great deal of astronomy has been done with instruments flown to date. The principle disadvantage of the satellite experiments, manned and unmanned, has been that their design and use had to be tailored to meet rather strict constraints dictated by the design and operations of the spacecraft with which they were integrated. In most cases, this has meant small size, rough pointing, minimal flexibility in data return, and a great deal of preflight testing to ensure high reliability. A very expensive experiment, which took several years to prepare, might then fail with no chance of reflight.

The value of rockets has been that a new object (e.g. Pulsars) could be studied (in the X-ray range) within a few months of its discovery (in the radio range), and examined in finer detail in a series of successive reflights. The cost of rocket experiments is small enough (∿$200K each) that support can be given to several groups to adapt their particular techniques to the object's observation.

SAS-A has discovered at least one new X-ray pulsar and a large number of x-ray sources (some highly variable) - fainter than could be located in a rocket survey flight. Its detector is the same type and size as those flown on rockets. It took about 4 years to prepare, however. Typical development times for other NASA astronomy experiments are:

OAO	∿ 8 years
ATM	> 5 years (right past solar maximum!)
Skylab corollary	3-7 years
OSO	∿ 3 years
Rocket/Balloon	< 1 year } (with improvements available between flights)
Aircraft	∿ 6 months }

With its general purpose design, OAO-A2 has collected a tremendous amount of preliminary data on thousands of stars. Similar studies, however, could have been carried out from rockets to comparable or better precision. The OAO-B would have employed a 1 meter (non-diffraction-limited) mirror. Unlike a rocket-borne telescope, it could not have been replaced cheaply even with back-up hardware. (Because of the need for high reliability,

the spacecraft cost ∿$100M. A 1 meter ground-based observatory of comparable flexibility might cost ∿$0.5M.) The disadvantage of a rocket experiment is the limited amount of time it has to acquire data. Its advantage is that it can be "customized" for a specific purpose.

Astronomical experiments conducted on a space station will probably suffer from many of the compromises now being encountered in the Skylab program, where there are conflicting orbit, orientation, integration and operational requirements placed upon the cluster. An advantage of a space station is that instruments can be serviced.

There are some types of research which will not be suited to the sortie operation. The spacecraft required will be expensive to launch into space, will be hampered by constraints and require expensive, high reliability instrumentation. They will therefore take a long time to develop and probably be flown as infrequently as in the current program. Some of the research included in this category follows:

i) Because of plasma noise limitations long-wave ($<200KH_z$) radio astronomy observations will have to be done in cis-lunar space outside the magnetosphere. An observatory in geosynchronous orbit may be valuable. The shuttle could carry such satellites with a kickstage and launch them from earth orbit, but observations during a shuttle sortie would not be possible.

ii) The sortie mode would not be capable of long-term uninterrupted monitoring functions (cf. OSO). The shuttle could, of course, deploy satellites for this purpose, and the sortie could provide continuity of opportunity by allowing repeated flights. In many cases the opportunity to improve the instrument between flights will be a distinct advantage and, if the sortie flight rate is sufficiently high, the interruptions may not be an unacceptable disadvantage.

iii) The sortie might not be suitable for atmospheric studies where the shuttle's orbital velocity limits the time it spends over a given geographical area. Although the shuttle cannot sound the atmosphere vertically, it could perform some of the variable-altitude probing planned for Atmospheric Explorer satellites, and perform sounding measurements during launch and return.

iv) The sortie mode will not be desirable as a regular observing platform for the large ASO, LST and OXO telescopes. The OAO and OSO programs have established the feasibility of continuous, automatic operations. (Stratoscope II is operated under real-time, remote-control by a ground-based team). Efficiency of pre-programmed usage should offset the disadvantage of having only one or two of this class of observatory for use by the whole world. The shuttle will probably be used to deploy and service these satellites and probably even to return them to earth for major modifications. The sortie will certainly be useful for the development work that must be accomplished to realize their optimum performance in much the same way that rockets are currently used for design verification of prototypes, for calibration and exploratory observations with instruments intended to eventually fly on satellites.

b) Use of the Sortie:

Observational

i) The sortie could conduct almost all astronomy observations now carried out with rocket-class experiments and piggyback satellite instruments. There does not seem to be any reason why an actual rocket payload itself could not be carried with little or no modification. In particular, the attitude control systems (e.g. the STRAP System developed by GSFC) now used on rockets are capable of better than 1″ pointing acquisition and stability and can be packaged to fit different rockets. Adaptation to airlock or pallet operation in a GPM should be relatively simple. In some cases, it might be desirable to simply set such a payload adrift and leave it in orbit.

ii) Experiments similar to Skylab corollary experiments could be flown.

iii) The grazing incidence, x-ray imaging telescope of $\sim$0.5m aperture to be flown on ATM would require little development to be adaptable for DM operation. Similarly, an OAO could readily be adapted to use in a DM.

iv) If suitable airlocks are provided, the sortie could make it possible to carry out a wide variety of observations with several moderate-sized telescopes (optimized for the wavelength region or technique) $\leq$1m in the GPM, and eventually a larger ($\sim$1-2m) telescope in the DM, supported by a variety of auxiliary equipment carried aboard by individual experimenters. If built according to ground standards, but

designed for use on a sortie, the cost of such telescopes would probably be less than the $2M-20M for larger ground-based instruments. A 1/2m telescope (20") is only slightly larger than the 15" telescopes now flown in rockets and should certainly be very inexpensive relative to an OAO and probably less expensive than Stratoscope II (∿$2M). A 1m telescope might be too large to operate from the GPM. However, several smaller telescopes could be operated simultaneously from pointed gimbal mountings attached to airlocks ≲1m in diameter in the GPM. These instruments could be standard equipment and suitable for mounting a wide variety of auxiliary equipment at the Cassegrain focus. Auxiliary equipment developed for GPM instruments would be available for use at any time a larger telescope were to be carried up in a DM. Simple, smaller instruments, such as XUV solar telescopes, or all-reflecting Schmidt cameras, could be mounted in smaller airlocks. For long focal-length solar and planetary telescopes, an arrangement similar to that shown in Figure 3 might be convenient.

v) The GPM airlocks should be able to permit large (∿3m x 3m) area micrometeoroid, X and γ-ray detectors to be extended and unfolded (mechanically or by EVA). The moon could be used as an occulting edge to give very high spatial resolution scans of some x-ray sources (of up to ∿2° extent @ ∿4π per sec.) on appropriatedly scheduled flights. The shuttle may be used to deploy and service the later HEAO satellites but they would usually not be operated in a sortie mode. Balloon-class experiments may require the larger aperture airlock of the DM, however.

Developmental

i) The evolutionary development of very large instruments can be supported by the GPM sortie. Smaller scale or engineering prototypes can be debugged and tested. Bread-broaded subsystems and electromechanical actuators can be tested in zero-gravity and the actual operating environment of space. The development of large observatories is likely to be protracted by economic and technological barriers. For comparison, it is estimated that a second 200-inch ground telescope would even require ∿10 years to build, using the proven Mt. Palomar design(1). The sortie could provide observing experience with diffraction-limited mirrors over a range of sizes, permitting more reliable extrapolation to larger sizes. Many of the problems which could combine to make all-up construction of a 3m diffraction-limited telescope difficult, might develop gradually and be dealt with more readily on the basis of this experience.

ii) Many elaborate ground-simulation tests may be replaced by test flights for debugging experiment hardware in the GPM, thereby eliminating a major cause of expense and delay in satellite development(especially large satellites).

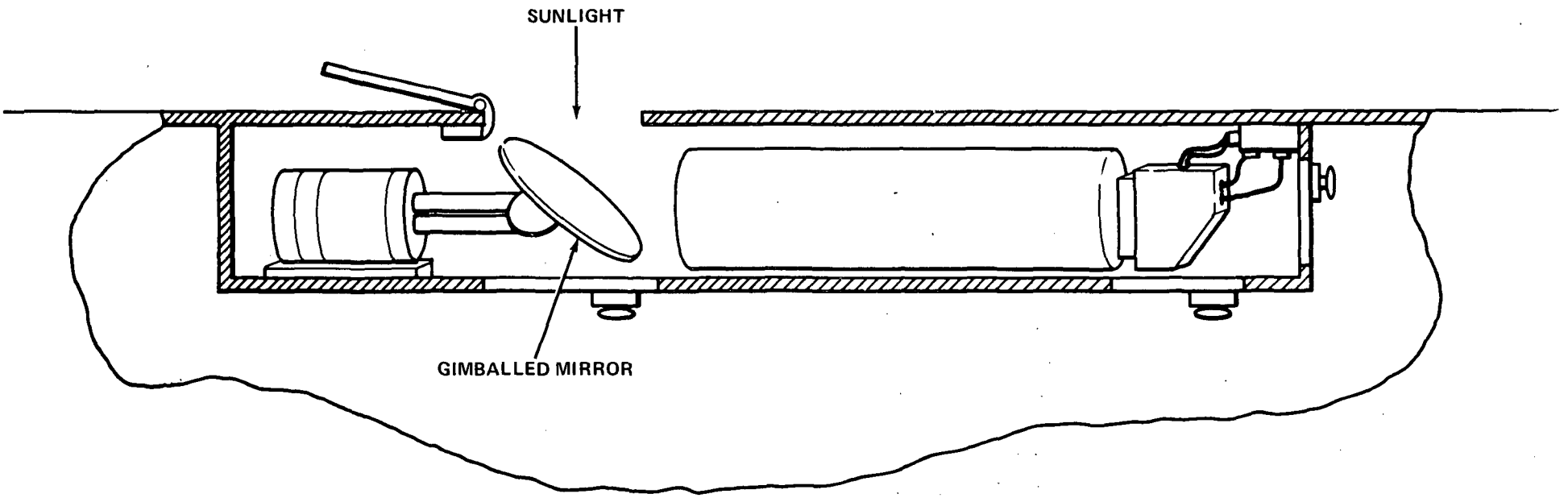

FIGURE 3 - LONG FOCUS SOLAR TELESCOPE

iii) The sortie would permit the natural growth of space astronomy research in gradual and continuous steps rather than short-lived bonanzas separated by long periods in which no data is being acquired. With a standard vehicle interface, the investment in an instruments' development would not be wasted simply because the next opportunity for flight requires a completely new configuration to fit into available payload space. Repeated observations to confirm results or make comparisons would be cheap and therefore require less rigorous justification.

iv) If short experiment lead-times are realized with the sortie program, it would eliminate the need for advanced, possibly premature, definition of large, integrated instrument assemblies similar to the ATM and those suggested for space-station modules. It is typical of long-lead-time programs that obsolete instruments are flown because it becomes so expensive to update such complex instruments after the integration phase has begun. In addition, if one experiment develops problems, it can hold up the flight of the others because of their physical interdependence.

v) The GPM sortie operation can reduce the number and size of organizations which are currently required to conduct space experiments. One of the principal causes of difficulties in space experimentation at present is the physical separation of the experiment from the experimenter, and the subsequent complications involved in making even slight modifications to the original concept during each of the several phases of its preparation and use. If the experimenters (or their representatives) could carry aboard their own equipment, fly with it and operate it, modifications could be made right up until flight and even in orbit. Data could be personally carried off at the end of the flight. It will then not be necessary to design and specify the exact use of an instrument for someone unfamiliar with the details of its operation and purpose. Automation of the quality now commercially available for use in laboratories would be much less expensive and probably more flexible and reliable than that qualified for such high reliability that it may not be removed from a clean room to work out unforeseen bugs. The effectiveness of the airborne and rocket programs has been credited to the relatively unstructured organization of experiment development.

Operational

i) Multiple airlocks in the GPM would permit simultaneous observations and sequential day/night-side operations without repeated removal and replacement of solar and stellar instruments. Sun-oriented instrument could be operated simultaneously to correlate solar and terrestrial phenomena if gimbaled optical platforms or mirrors were extended through airlocks.

ii) Experiments which require consumable supplies, in particular, liquid helium, could be supported for the duration of a sortie mission. This is particularly important for IR astronomy where the entire telescope will have to be cooled.

iii) Current manned and unmanned programs cannot meet the demand for individual space experiments, and cannot afford to increase the opportunities. For example, OSO's are oversubscribed by roughly a factor of 2, yet carry instruments small enough to be easily operated at a GPM airlock. These conditions are likely to continue. A GPM sortie, organized for a particular purpose, such as an all-solar expedition (or a cometary, planetary, auroral or supernova-dedicated flight) could enable a wide range of coordinated studies to be made simultaneously from one vehicle, with the orbital parameters, spacecraft orientation and other operational factors tailored to that purpose.

iv) The GPM sortie would permit wide and uncomplicated participation by graduate students, ground-based astronomers and foreign investigators, thereby increasing the number of people able to exploit and interpret the opportunities provided by space observations, especially those who are "problem-oriented", rather than "hardware oriented". This would permit fuller cooperation between space and ground observations. At present, groups conducting satellite observations are often swamped with unanalyzed data at the same time they are busy operating the current satellite and preparing a next generation payload; the pressure to meet schedules is very strong because of the size of the system now required to get good data back from space, and because of the infrequent opportunity.

Since space telescopes are extremely vulnerable to contamination, by even their own outgassing, it would be an advantage to be able to replace their optics in orbit or return them for recoating on the ground. (Although the OAO-A2 telescopes seem to have escaped contamination it has been found on OSO instruments.) The ability to provide inflight calibration with laboratory standards would be advantageous. Although television detectors will be greatly improved, film will probably remain superior for image recording for some time to fully exploit diffraction-limited performance. It can be recovered from a sortie mission and test exposures could even be developed onboard.

Most space astronomy observations do not require manned operation. Some observations, as in a crowded field, or involving faint, complex, small or low contrast features, may require an observer to select the points of measurements.

New techniques (e.g. IR astronomy) however, generally require constant attention to a number of elements which could be automated, in principle, but at a cost in time and design effort which is objectionable to someone whose principal interest is the problem being studied. Many expensive-to-automate functions (e.g. focusing) can be simply carried out in person, especially by a person familiar with the instrument and its eccentricities.

v) Illustrative Example

If the shuttle were operational at the present time, what sort of simple instrument might be of great value and be ready within one year for a GPM sortie flight?

An electronographic ultraviolet Schmidt camera† (See Figure 4) similar to the Apollo 16 ultraviolet Lunar Surface Camera (S-201) could be built at relatively low cost and acquire superb data on a GPM sortie.

This type of instrument has been flown on about 8 rocket flights of which 3 failed for reasons unrelated to the instrument. Various configurations have been flown (corrector plate Schmidt: 2" and 3", f/2 and 4" f/1.5; Schwarzschild: 6", f/1.6 and f/3.2) with an objective grating and without. Past flights have provided high resolution (up to 0.3Å) objective spectra of wide fields (7°-20°) of stars to 5th magnitude and direct photographs to 8th magnitude. The instrument has been successful in discovering interstellar molecular hydrogen, measuring interstellar atomic hydrogen abundances, and recording unusual characteristics in the spectra of stars in the wavelength range 950Å to 1600A. The Apollo 16 version is a 3",f/1.0 Schmidt camera to study the cosmic ultraviolet background, and will cost $\gtrsim$1.2M.(18)

For a sortie flight, the instrument could be pointed by eye, and with reasonable steadiness of the shuttle, a rocket pointing system could hold it steady to $\sim$1". It could be made as a 6", f/2 conventional Schmidt or 3", f/2 all-reflecting Schmidt. Because of its high speed, a single exposure would record to fainter than 12th magnitude which, for a 10° diameter field-of-view, would include hundreds of stars, providing spectral data on each star of quality comparable to what could have been obtained from OAO-B.

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†In an electronographic camera, the light image is converted to an electron image which is recorded on an electron-sensitive emulsion.

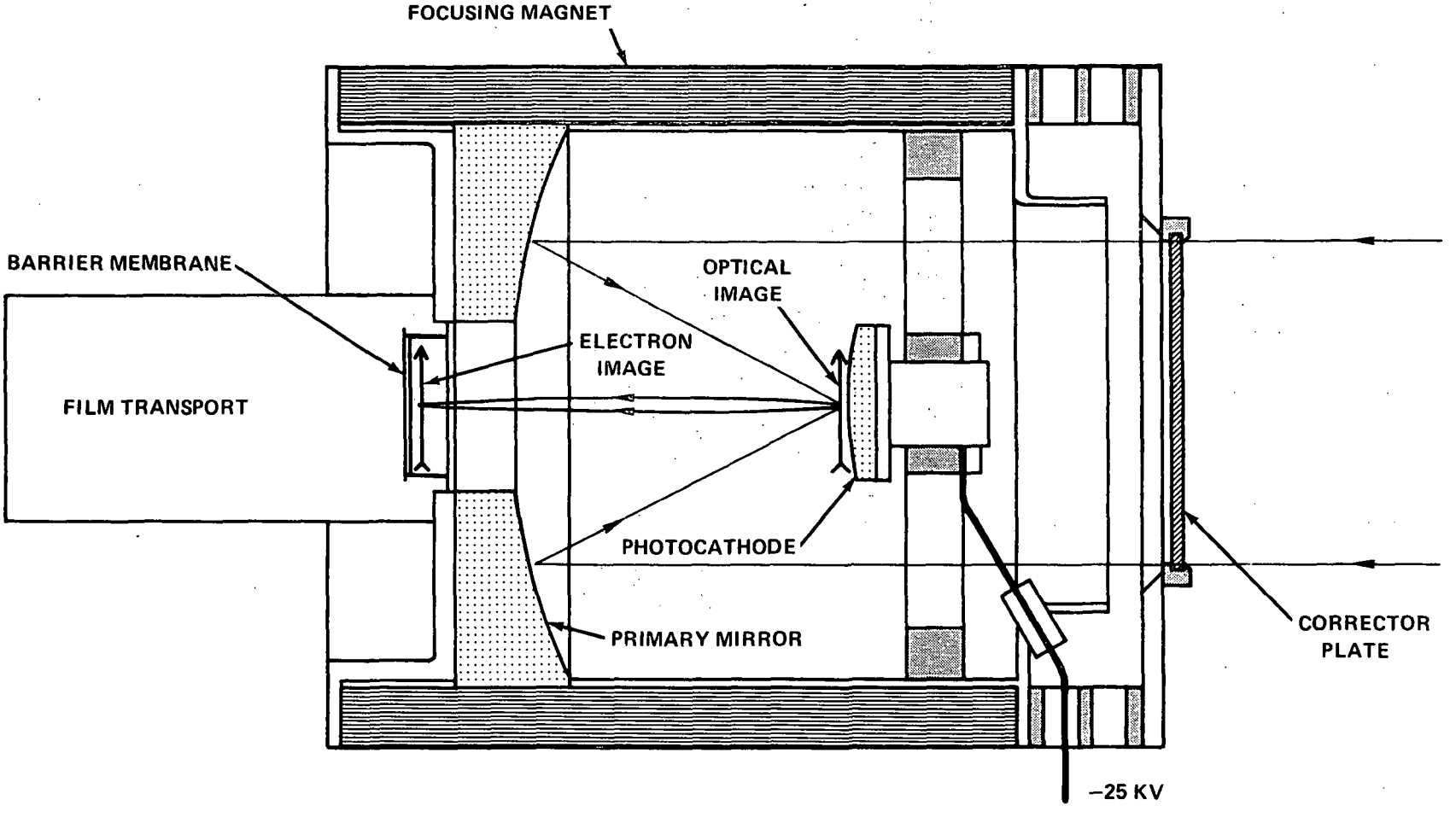

FIGURE 4 - SIMPLIFIED CROSS-SECTION DIAGRAM OF THE ELECTRONOGRAPHIC SCHMIDT CAMERA

It is estimated that the sortie instrument would take roughly one year to build and cost ∿$100K including the experimenter's salary. Each reflight would cost ∿$100K, and could be made about 1 month after a previous flight. The instrument would be built by the experimenter.

The entire telescope would weigh ∿75#, be about 3 feet long and have an overall diameter of about 12". Its power consumption would be 2 watts average, 50 watts maximum (during film transport pulses). During the sortie, the experimenter could calibrate the instrument with a portable UV standard; change objective gratings, UV filters and photocathodes; broaden the spectra optimally, and sharpen the focus by adjusting the electron accelerating potential. He could make test exposures, develop the film and determine the most useful exposure times. He could then, for example, proceed to systematically photograph large areas of the galactic plane to produce mosaics covering nebular complexes such as the Gum nebula. He could obtain direct photographs in different wavelength bands of the Magellanic clouds or the Andromeda galaxy to study the ultraviolet brightness across their surface.

The particular advantage of this experimenter's presence onboard would be his experience as a pioneer in the development and use of this new type of instrument in space, his motivation to acquire significant results and his sensitivity to the subtle balance of factors which determine the ultimate quality of his data.

For the Apollo 16 instrument, approximately 100 documents were required, varying in length from 2 to 60 pages, of which from 4 to 10 copies of each were required by NASA. Many of these were management instruments useful only for much larger programs. An estimated 30% of the $1.2M development support to the experimenter was required for such documentation. Much of the documentation passed through several review interation cycles before it was accepted and it occupied several people full time. By comparison, documentation for a rocket flight is minimal; requiring several days for the preparation of the experiment proposal, the project directive to the range, and attendance at several meetings with flight support personnel.

Several proposals have been submitted for a larger version of this instrument, suitable for a stellar ATM. With a speed gain of ∿10-30 over normal photography, a 1/2m version would be faster than the 48" Schmidt on Mt. Palomar.

There are other examples of flight-proven rocket and balloon experiments which would be available, on short notice,

for the sortie flight. On the GPM sortie, exposure times and flexibility superior to rocket flights would be possible. The potential for growth to larger versions would be readily available.

VI. Astronomy Traffic for the Sortie

Will there be a sustained demand for flights in the GPM sortie?

Approximately 12-15 experienced groups are currently active in rocket astronomy in the United States. There are roughly 30-60 astronomy flights per year. Assuming that the rate is doubled, as has been recommended, 6 to 12 sortie flights per year could be occupied with this activity alone if 10 experiments could be operated in a GPM. If the cost and effort to participate can be directed to scientific aspects of the experiments and not mainly to their conversion for use in the GPM, there should be a growing demand for the foreseeable future. If, significant research is accomplished in the initial period, and a number of experimenters accompany their instruments, a great deal of attention will be focused on the opportunities of the sortie mode. This should be very likely, in view of the great improvement in flexibility and exposure time available relative to a rocket flight. Even in the event of instrument failures, the opportunity for reflight would make the investment of effort worthwhile and engender faith in the program. As more people participated in the flights, they would stimulate a wider awareness of the sortie's possibilities. There are about 3000 professional astronomers in the United States. In this country, there are approximately 1000 members of the International Astronomical Union, membership in which represents recognition for astronomical research. It is reasonable to expect that a strong interest in participation would be forthcoming from this community and from related disciplines - an interest now discouraged by the difficulties of space research.

Graduate students and university astronomers would probably be attracted to the sortie program as it develops in effectiveness and becomes routine. For a graduate thesis, an observational program must be cheap and have a reasonable certainty of being completed in 1/2 to 1 1/2 years. In the United States there are about 700-800 graduate students in astronomy alone, some fraction of whom would certainly be enthusiastic about sortie research.

The competitive advantages to sortie experimenters would be so immediately apparent that foreign scientists would be attracted and the program would open to world-wide participation. There are about twice as many foreign

members in the IAU as there are U. S. citizens. If foreign countries could outfit a GPM module for themselves a large demand for shuttle service (including satellite deployment) is liable to develop.

The relative ease with which growth could be accommodated, from an exploratory instrument in the GPM to a fairly large instrument in a DM, should encourage advances in detector techniques which will draw off some of the traffic destined for the very large observatories. For example, success with an electronographic auxiliary instrument on a 1/2 m GPM telescope could be immediately exploited with a 1 or 2m near diffraction-limited telescope in the DM. The factor of 10-30 advantage in speed over regular photography could place a 1m telescope on a par with a 3m telescope in signal gain, long before a 3m observatory is available. Some studies previously requiring a 3m telescope could then begin on the 1m telescope.

In a similar manner, some experiments now considered to be appropriate only for satellites are likely to be adapted for use on a sortie because of the simplicity of participation. The results of familiarity and ingenuity are bound to dramatically alter the space astronomy picture from what is currently imagined.

VII. Astronomy Requirements on the Sortie Program

In what way will the use of the shuttle sortie for astronomy impact the configuration of the shuttle vehicle, the experiment modules and the sortie operations?

The value of the sortie program to astronomy will be great, especially if it is readily adaptable to the diversity of observations likely to be desired. This requires that the foreseeable needs for astronomy be taken into consideration in the original design of the shuttle system, and that this design stress simplicity of accommodation.

a) Impact on Shuttle Vehicle

i) It is essential that the vehicle be capable of holding any orientation for extended periods of time, up to almost the full duration of a flight. The vehicle should not be restricted to only certain orientations because this would preclude certain directions of view. The requirement for long term holding is imposed by the availability and value of very long exposure (up to many days) on targets close to the orbital-plane normal direction. High stability is valuable, but a ±0.1° deadband could be accommodated by telescope pointing systems. A controlled, slow rotation mode would be useful

for scanning high energy detectors.

ii) Accurate aspect data should be accessible to experimenters as a normal monitoring function. The position, altitude and orientation of the vehicle should be continuously recorded, as well as displayed, to the observer for efficient operation of telescopes. Some convenient means to slew the vehicle orientation would be useful, especially when a number of different sources are being compared. Small displacements would be handled with gimballed telescope mounts.

iii) To avoid the danger of optical surfaces contamination by thruster exhausts, the orientation may have to be maintainable without resorting to reaction jets. This may require a CMG auxiliary pointing system. Waste dumps must be strictly controlled for the same reason. In addition, both jets and dumps are sources of scattered light.

iv) The materials of which the vehicle is made (e.g. refractory metal heat shields) must have a low level of natural radioactivity, and RTG power sources may not be acceptable because of their potential interference with high-energy detectors. Shielding and anti-coincidence protection may relieve this restriction.

v) There will have to be a way to jettison extended experiments† to ensure the closing of the shuttle payload-bay doors. EVA may be a necessary option. EVA would also be invaluable for unfolding large arrays and attaching irregularly-shaped instruments on external pallets.

vi) An important issue for astronomy is the diameter of the payload bay, because it limits the length of instruments which can be readily mounted in the airlocks. Rocket payloads can be up to 3m in length. A 1m, f/2 Cassegrain would also be about 3m long. If a pressure vessel, or room to handle equipment at the focus of the telescope is to be provided, the space required could extend about 4m in from the experiment module wall. Folded optics (See Figure 3) could shorten this distance where the extra reflections do not reduce the signal excessively ($\lambda \gtrsim 1100$Å). A 1/2 m, f/10 grazing-incidence x-ray telescope, however, would be at least 5m long. If mounted at the airlock with a 45° adapter flange, it would extend about 3.5m in from the wall. A 3m diameter optical telescope mirror (or prototype observatory) would have to be mounted with its optical axis along the length of the module and would require an experiment module somewhat larger in diameter than 3m.

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†For example, in the event they become jammed and cannot be retracted.

If experiments are to be stored elsewhere and maneuvered into the airlocks or pressure vessels for operation, a large diameter module will be a distinct advantage.

vii) The shuttle should be capable of flight at any orbital inclination to permit extended observation of any point on the celestial spere. In particular, a polar, sun-synchronous orbit would be needed to avoid interruption of solar observations by earth occultation every orbit.

viii) For coverage of a full rotation of the sun ($\sim$27 days) and a full lunar phase cycle ($\sim$29 days) up to one month flight duration would be valuable.

ix) If the sortie program is to effectively replace the rocket program, it is essential that the present capability for rapid follow-up of discoveries not be lost.

For rapid response to solar events, supernova appearances, and to support planetary probe encounters, flexible launch scheduling would also be valuable.

x) The capability to modify the orbit altitude in mid-flight could be useful in an astronomy or atmospheric observation sortie. If the presence of contamination around the vehicle proves to be a scattered light problem (especially for infrared observations), a continuous low level of acceleration may be useful to prevent its accumulation.

b) Impact on the Experiment Modules

i) The airlocks for the GPM and the DM are critical design elements. All astronomy observations will be made through airlocks and a major threat to a strong astronomy sortie program is that the size and number of airlocks will be inadequate. Because their operation will be so frequent, they must be accident-proof against any possible leakage or failure in the instruments; this may require pressure vessels (See Figure 3) rather than flanged airlocks if a simple interface is to be retained.

The size of the airlocks limits the aperture of telescopes which can be operated through them and there should be several as large as possible ($\gtrsim$1m in the GPM, $\sim$2-3m in the DM), since provision for an accurate pointing control system must be made and mounting procedures must remain simple. Thermal control must also be available to prevent excessive temperature changes in the instrument on both the sun side and dark side of the vehicle. It should be possible to meet these requirements without sacrificing too much aperture and a simple interface between instrument and airlock.

ii) Power requirements of astronomy experiments are small. Each experiment might require a few hundred watts for the instrument and rack-mounted supporting equipment. Each telescope may weigh up to several hundred pounds and may have to be stored, during shuttle launch and reentry, rather than left mounted at an airlock. A large DM telescope might be as heavy as 10^4 pounds (OAO and balloon payloads weigh 2000-5000 pounds).

iii) If access to a DM were available from the GPM, an auxiliary instrument could be replaced by hand on a large telescope; or a general-purpose pallet could have different instruments mounted on it for extension out into space. This would likely be most useful for rocket and balloon payloads which have undergone little or no modification for sortie operation and cannot easily be mounted in a regular airlock.

iv) The crew size should be flexible and would probably have to be limited to smaller numbers for longer missions because of crowding and consumable storage requirements. In a GPM-only sortie, the crew-support emphasis should be more like 10-15 men and women for 4 weeks than 2-4 men for 5 days. With a large number of small instruments, or when a large number of observing programs are to be conducted with different auxiliary instruments, experimenters might operate several experiments besides their own, but it would be preferable to have a small team, or at least one person, for each instrument.

c) Data Management

i) The recording of data should be as flexible as possible. Some experimenters will record all data on film or rack-mounted, magnetic and strip-chart recorders. Some will require a small, programmable computer (e.g. PDP-8, ∿$7K, ∿65 pounds) to partially process and condense the data. Others will want to store every bit and dump it to the ground for storage. This is particularly likely with large DM instruments.

ii) In some cases, near real-time T.V. down-link transmission will be wanted from an optical input on a telescope, (with convertors for non-visible wavelengths).

iii) For coordinated ground-and-space observations, high-precision, synchronized clocks and real-time communications will be needed.

d) Miscellaneous Requirements

i) Some degree of screening and training will be necessary to familiarize non-astronaut experimenters to working in the zero-g environment. A training program lasting ∿3 months would appear to be realistic. This would correspond to say, a summer session at a training center. At the same time, a course might be given by astronauts and experienced experimenters on safety procedures, available equipment, recommended techniques etc. A user's handbook should be developed and include designs of flight-proven experiments. The success of an experiment would then become the experimenter's responsibility.

ii) Control of fluids in zero-g will be necessary in order to properly handle cryogenic coolants and film-processing chemicals during a sortie.

iii) Light scattered into a telescope from the sun, earth and moon could limit the accessible areas of the sky (especially for IR telescopes) and restrict exposures to the dark side of the orbit. External baffles will be needed to reduce scattered light and, in particular, to permit observations close to the horizon, for extended exposures near the orbital poles.

In summary, astronomy experiment requirements have a major impact on the design and operation of the vehicle and the experiment modules.

VII. Summary and Conclusions

Space observations promise to greatly influence every aspect of astronomy. A large variety of space instruments will be required to carry out the many types of new studies possible. Small instruments are required for many purposes, especially during exploratory phases of any study, but there is an essential need for larger instruments because aperture size is the factor limiting what can be seen. A 1m advanced solar telescope, a 3m diffraction-limited optical telescope, and a 5m focusing x-ray telescope have been recommended as the most highly prized goals for the space astronomy program. The advanced solar and x-ray telescopes may become available, by extension of the OSO and HEAO programs, before the sortie is operational. The LST, however, because of its cost and complexity, is likely to be deferred until its development can be supported with the shuttle.

A great deal of research and, in particular, much of the supporting work for the large observatories, both developmental and observational, could be conducted on sortie flights. The sortie program is not suitable for their routine operation, however. A variety of powerful, medium-size telescopes and arrays could be operated on a sortie; as large as ∿1/2m in the general purpose module airlocks and up to 2m in a dedicated module observatory. These instruments would permit a full range of research to be conducted and could provide data and equipment important in the development of the sophisticated space observatories. Almost all of the research for which an expanded rocket program is desired could be carried out in the sortie program.

It is certain that improved techniques will extend the performance of the sortie instruments, thereby somewhat relieving the pressure for the balance in instrument size to shift to larger sizes.

To conduct astronomy sorties, the shuttle, both types of experiment modules and the sortie operation will have to be designed to satisfy several significant requirements and be adaptable to others to be truly effective for a long term astronomy program.

Some specific conclusions follow:

i) Current analogous programs, the Skylab, ATM, OAO and the C-141 IR airborne observatory in particular, should be compared as guides to develop a clearer idea of the most useful sortie program.

ii) All support for the development of detectors with improved guantum efficiency, spatial resolution and integration capacity is a very productive investment relative to the cost of constructing larger aperture telescopes.

iii) The sortie program could make space astronomy routine by permitting astronomers to participate without extensive experience in space observations, by providing opportunities for coordinated ground and space projects, and by enabling auxiliary equipment and back-up apparatus, identical to that which has been developed for ground-based work, to be operated in space, and vice versa. A community-wide desire to participate is likely to develop.

iv) The cost of the astronomy sortie program could be small relative to the investment required for the development of the large orbiting observatories. The smaller instruments will be needed to assist in development work and to carry out the variety of studies for which the large telescopes are either not essential or not suitable (e.g., for XUV and IR observations).

v) Because of the sortie's great potential value to astronomy, it is important that the needs of astronomy be considered in the vehicle design and sortie program definition. Astronomers and other scientists should be consulted as early as possible. Groups representing the viewpoint of various disciplines could study the program in detail and make recommendations on the basis of their interests.

VIII. Acknowledgments

Many people contributed to the ideas expressed in this report. Some were skeptical, others were enthusiastic, but all were helpful. I wish to thank them, especially Messrs. G. T. Orrok and D. B. Wood of Bellcomm, for their support and recommendations.

N. Paul Patterson

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N. P. Patterson

Attachments
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Appendices 1-3

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APPENDIX 1

Objectives of Astronomy

The variety of subjects of interest to theoretical and observational astronomers is very large.(1,9, 10) The following outline is therefore intended only to typify the targets and topics.

These objectives are pursued in order to find answers to such fundamental questions as:

* What is the nature of the universe? What is its present structure? What was its origin and how is it evolving? What are the physical laws which govern it?

* What is the nature of life? How did it originate? Is there life elsewhere in the universe? Where?

Targets	Topics(typical)
Cosmological Indicators	New Concept of the universe? Is the universe closed or open? Size of universe New laws of physics? Creation of matter, anti-matter? Clustering of galaxies Formation of galaxies Redshifts, doppler and non-doppler IR, Microwave backgrounds X,γ-ray, UV backgrounds Intergalactic medium, fields.
Galaxies	Distance calibration Luminosities Stellar populations, dynamics Normal/unusual structure, evolution Explosive events, energy sources IR, UV excesses Nuclei of galaxies Element abundance Many-body interactions

Targets	Topics (typical)
Special Objects	Nature, locations? X-ray, γ-ray, IR sources Quasars, Black holes(?) Pulsars (neutron stars?) Radio sources Crab Nebula and Pulsar Gum Nebula and Pulsar Orion Complex Magellanic Clouds Andromeda Galaxy New objects?
Stars	Age, origin, location, interactions Formation, evolution, proto-stars, dead stars Normal, pecular, variable, explosive Flare activity, oscillations, rotation Stellar winds, atmospheres, fields Novae and supernovae Distance calibration Element abundance Radio Stars, Magnetic Stars Planetary systems
Solar System	Origin, evolution Planetary atmospheres, surfaces, structure, processes Comets, asteroids, dust, solar wind Interplanetary fields Jupiter radio-emission, non-thermal Mars, conditions. Life? Other planetary systems Stellar occultations Celestial Mechanics
Sun	Origin, evolution, structure Cause of Solar cycle, magnetic fields, sunspots

Targets	Topics (typical)
Sun (cont'd)	Chromospheric heating mechanisms Corona, solar wind structure Energy transfer mechanisms: radiative, kinetic, collective motion Spicules, plages, flares, prominences, granulation Plasma magnetohydrodynamics Energetic particles, acceleration Energy generation, storage, release
Earth	Solar-terrestrial, relationships Airglow and aurorae Ozone and upper atmosphere structure Atmospheric composition, photochemistry Meteors, meteorites Atmospheric extinction, absorption

APPENDIX 2

Probable Instrumental Requirements for Space Astronomy (9,10)

a) Photon Collectors

Optical Telescopes	• Schmidt (all reflecting UV and visible) • Cassegrain (UV through IR) • Solar (UV through IR) • Coronagraph (XUV through IR) • Far IR (cryogenically cooled) • XUV solar, planetary telescopes
High-Energy Telescopes	• X-ray grazing-incidence, imaging telescope • γ-ray Cerenkov telescope • X- and γ-ray arrays (erectable): proportional counter scintillation counter spark chamber emulsion stack
Radio Telescopes	• Very long baseline interferometer • Kilometer wave orbiting telescope

b) Auxiliary Instruments

- Spectrographs (x-ray through visible)
- Photometers; narrow band, filters, (all wavelengths)
- Spectrometers; scanning and multichannel (all wavelengths)
- Interferometers; spatial and spectral (particularly IR and radio)
- XUV, X-ray, grazing-incidence grating and crystal spectrometers
- Photographic cameras; plates and cine (x-ray through visible)
- Photoelectric image scanners and detectors (x-ray through IR)
- Electronographic cameras (x-ray through IR)
- Photoelectric image convertors and intensifiers (x-ray through IR)
- Echelle spectrometers (especially UV and visible)
- Polarimeters (all wavelengths)
- Single photon counters (γ-ray through visible)

c) Component Development

- Large, efficient gratings (UV through visible)
- Large, low-noise, cooled solid-state detectors (γ-ray and IR)
- Improved television tubes (x-ray through IR)
- Filters (x-ray through IR)
- Solid-state imaging detectors (expecially IR)
- Coherent detectors; tuneable masers and lasers (especially IR and radio)
- Improved photographic emulsions (γ-ray through near IR)
- Onboard absolute calibration
- New types of detectors

d) Technological Developments

- Near-diffraction-limited optics ($\sim \lambda/50$ figure precision)
- Mirror figure stability and maintenance
- Thermal control
- Pointing control (jitter $\sim$10% of angular resolution)
- Cryogenic fluid control
- Materials stability
- Onboard film manufacture, development; mirror coating,
- Maintenance
- Data management
- Shading and Baffling

e) Observational Factors

- Sky backgrounds (all wavelengths)
- Scattered light
- Optical contamination
- Radiation belt noise, damage
- Interstellar transparency (especially 100-912 Å)

Appendix 3

Current Astronomy Programs

The following is a summary of astronomy programs, including spacecraft and experiments which will probably have all been completed by the time the shuttle sortie becomes operational (c.1980).

It is likely that other programs will be started which are not listed and some programs shown may be continued with additional spacecraft not yet planned (e.g., OSO,SAS).

The cost estimates given are approximate and intended for illustration only.

Suborbital:

Balloons

i) Large, heavy, cosmic ray, hard x-ray and γ-ray experiments, Stratoscope I (12" solar telescope) and far - IR telescopes ($\sim$30cm operational, 1m. under construction). Observing time $\sim$10 hrs. Residual Atmospheric mass $\lesssim$ 3gm/cm^2. Experiment costs $\sim$\$100K, Trip costs \$5-50K, several flights per trip.

ii) Stratoscope II, visible, near-diffraction-limited ($\sim\lambda$/40rms) 36" primary. Pointing stability $\sim$0.02"rms. Resolution $\lesssim$ 0.2". Development Cost $\sim$\$2M, Trip costs $\sim$\$1M. Observing time $\sim$8 hrs.

Aircraft

i) CV990: International auroral, Solar eclipse and Mars sortie expeditions. Experiments cost $\sim$\$50K each. Trip costs $\sim$\$30K each. Each sortie 10-15 experiments, $\sim$20-30 experimenters. IR, visible only. Flight costs $\sim$\$2K/hr. Observing time $\sim$5 hrs.

ii) Lear Jet: Solar visible, 8" telescope. IR telescopes, 8" and 12", cryogenically cooled, for point sources only. Instrument costs $\sim$\$100K. Trip costs $\sim$\$5K. Flight costs $\sim$\$200/hr. Observing time $\sim$2hrs. Several flights per trip.

iii) C-141: 36" IR telescope under construction. Cooled detectors. Observing time $\sim$3hrs. Point sources only. Instrument cost $\sim$\$4M. Flight costs $\sim$\$1K/hr.

Rockets

Approximately 50-100 domestic and international flights per year for solar, stellar, auroral and planetary (UV, IR,X-ray) studies. IR: cooled telescope, point sources and diffuse background, λ=25μ to 1mm. Payloads $\sim$2m x 0.4m diameter, weight 100-300#. Payload cost $\sim$\$200-500K, Reflight $\sim$\$100K. Observing time $\lesssim$5 minutes. Effective for space instrument development, surveys and bright source studies.

Unmanned Satellites:

Past

i) OGO I-VI: Numerous (international) piggyback detectors to study UV airglow and backgrounds. Spacecraft cost $\sim$\$40M each.

Ongoing

ii) OSO I-VII; Numerous ($\sim$6 per spacecraft) small solar (X-ray, XUV, UV, visible) instruments, X-ray cosmic backgrounds and spectrum. OSO I,J,K will be re-designed and have larger, improved instruments. Spacecraft cost $\sim$\$15-30M each.

iii) Solrad, I-X: Solar x-ray and UV monitoring detectors. Spacecraft Cost $\sim$\$3M each.

iv) OAO A1, A2, B(C): A1 and B failed. A2 observed with several UV telescopes 8"-12". (16" failed). Operating $\sim$3 years, many discoveries. OAO-C will carry a 32" UV telescope and small x-ray detector. Spacecraft cost $\sim$\$100M each. Much technology available for future program, including designs for shuttle servicing.

v) SAS-A(B,C,D?) Small x-ray and γ-ray detectors for scanning sky. SAS-C will be pointed. Spacecraft cost $\sim$ \$15M each.

vi) RAE-A,B Radio astronomy telescopes. RAE-A is in earth orbit. RAE-B will be put in lunar orbit in 1973. Spacecraft cost $\sim$\$10M each.

vii) Mariner IV-IX,J Planetary probes. Multiple instruments, UV through radio. Studying details of planetary atmosphere and surface (Venus and Mars) and galactic Ly-α background. Spacecraft cost $\gtrsim$\$60M each.

Impending

viii) AE-C(D?,E?). Orbiting atmospheric probes to study photochemistry of earth's upper atmosphere. Spacecraft cost ∿$15M each.

ix) AEROS - German satellite to study upper atmosphere photochemistry. One NASA-funded experiment ∿$1M.

x) ANS - Small Netherlands UV and X-ray observatory.

xi) UK-5 - Small British x-ray observatory.

xii) Pioneer F, G. Jupiter Probes. Spacecraft cost ∿$50M each.

xiii) Viking A, B. Mars orbiter and lander. (Project cost ∿$800M).

Planned

xiv) HEAO A,B(C): Large area X-ray, γ-ray and particle detectors for surveying sky. A and B will not be pointed. A third spacecraft may have pointing and be designed for shuttle launch and servicing. Spacecraft cost $75-100M each, weigh∿12,000 pounds each.

Manned spacecraft:

i) Apollo 15: Gegenschein and Ultraviolet photography. Lunar atmosphere UV spectrometer (Instrument cost∿$2.5M).

ii) Apollo 16: UV Lunar Surface telescope, 3",f/1 Schmidt with electronography for studying geocorona, solar wind and galactic UV backgrounds. Instrument cost ∿$1.2M.

iii) Skylab Corollary: †
S-009- Nuclear Emulsion - Heavy Nuclei Cosmic ray tracks. Experiment cost ∿$0.7M.
S-019 and S-183 - UV telescopes,∿6" aperture for stellar spectral photography. S-183 is provided by France. S-019 cost ∿$2.9M.
S-020 - Solar XUV spectrograph. Cost ∿$0.9M.
S-063 - UV and visible photography of upper atmosphere. Experiment cost ∿$1.8M.
S-073 - Gegenschein and Zodiacal light photometry. Experiment cost ∿$7M.

S-149 - Micrometeoroid Collector. Experiment cost ∿$0.7M.
S-150 - X-ray detector for scanning sky. Cost ∿$0.5M plus funding for earlier version.

iv) Skylab ATM - Six high-precision solar telescopes (X-ray through visible). Resolution $\sim 5''$-$15''$, $\lesssim$0.2Å. ATM cost $\gtrsim$\$250M including supporting systems.

† Costs shown are for experiment development and data analysis only and do not include SR&T funding prior to approval, or integration costs.

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Sortie - Case 236

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N. G. Roman/SG
A. W. Schardt/SG
F. L. Williams/AAD-2
R. G. Wilson/SF
R. J. Wisniewski/RX

ARC

M. Bader/SS
R. M. Cameron/SSO
D. H. Dennis/M
L. C. Haughney/SSO
D. R. Mulholland/SSS

GSFC

A. Boggess/613
J. E. Kupperian/613
J. Purcell/410
W. E. Stroud/110
D. B. Wood/110

KSC

H. E. McCoy/FP-B

MSC

K. G. Henize/CB
R. A. Moke/TD4
J. G. Zarcaro/TD

MSFC

J. A. Downey/PD-MP-DIR
H. P. Gierow/PD-MP-DIR
J. H. Waite/PM-SL-DP

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I. M. Ross
R. L. Wagner